PATENT SPECIFICATION

DRAWINGS ATTACHED

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925,541

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Date of filing Complete Specification Jan. 8, 1960.

Application date Jan. 22, 1959. *No. 2492/59.*

Complete Specification Published May 8, 1963.

Index at acceptance:—**Class 40(7), G(1A:4C:7T).**

International Classification:—**G01h.**

COMPLETE SPECIFICATION

Improvements in or relating to Ultrasonic Flowmeters

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by Statute, of 1 Tilney Street, London, W.1, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to ultrasonic flowmeters, and provides means for measuring the rate of flow of a fluid by measuring the change of frequency in a beam of ultrasonic waves due to the Doppler Effect.

An ultrasonic flowmeter is known, for example from our British Patent Specification No. 855,650, for measuring the rate of flow of a fluid medium in a pipe comprising at least one pair of electro-acoustic transmitting and receiving transducers together with associated coupling blocks for transmitting ultrasonic waves by two paths extending across the pipe, one path directed upstream of the fluid flow and the other directed downstream of the fluid flow, in which ultrasonic compressional waves are generated in the fluid medium by shear waves generated in the transmitting coupling block or coupling blocks.

The present invention relates to a type of ultrasonic flowmeter for measuring the rate of flow, relative to the flowmeter, of a fluid containing scattering elements which reflect ultrasonic waves.

According to a first aspect, the present invention provides an ultrasonic flowmeter comprising a transmitting transducer arranged for directing a beam of ultrasonic waves into a body of flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, a receiving transducer arranged for receiving a part of the scattered beam, a solid body through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, and means responsive to the difference between the frequency of the waves transmitted by the transmitting transducer and the frequency of the waves received by the receiving transducer, the said frequency difference being representative of the rate of flow of the flowing fluid, the solid body being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

According to a second aspect, the present invention provides an ultrasonic flowmeter comprising a transmitting transducer arranged for directing a beam of ultrasonic waves into a body of flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, a receiving transducer arranged for receiving a part of the scattered beam, a fluid medium, other than the flowing fluid, coupled to the transmitting transducer for transmitting the beam, a solid body through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, and means responsive to the difference between the frequency of the waves transmitted by the transmitting transducer and the frequency of the waves received by the receiving transducer, said frequency difference being representative of the rate of flow of the flowing fluid, the said fluid medium coupled to the transmitting transducer being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

According to a third aspect, the present invention provides a method of measuring the rate of flow of a flowing fluid, comprising the steps of directing a beam of ultrasonic waves from a transmitting transducer into a body of the flowing fluid containing beam-scattering elements, at an angle to the direction of flow

other than 90°, and receiving a part of the scattered beam, either by the said transmitting transducer or by a separate receiving transducer, the arrangement being such that the beam of ultrasonic waves is generated initially by the transmitting transducer in a solid body, through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, the solid body being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the fluid, so that the difference of frequency between the transmitted waves and the received waves provides a measure of the rate of flow of the flowing fluid.

According to a fourth aspect, the present invention provides a method of measuring the rate of flow of a flowing fluid comprising the steps of directing a beam of ultrasonic waves from a transmitting transducer into a body of the flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, and receiving a part of the scattered beam either by the said transmitting transducer or by a separate receiving transducer, the arrangement being such that the beam of ultrasonic waves is generated initially by the transmitting transducer in a fluid medium other than the flowing fluid, and the said beam is directed into the flowing fluid by refraction at the interface between the flowing fluid and a solid body, the said fluid medium being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

Flowmeters according to the invention have special advantages, in that they provide means for introducing the beam of ultrasonic waves into the flowing fluid in such a manner as to compensate for changes of the velocity of sound in the flowing fluid.

The scattering elements referred to are small, often minute, regions in the flowing fluid having a different sound transmission characteristic from the surrounding parts of the fluid and therefore causing reflection of the ultrasonic waves. Such scattering elements are already present in many flowing fluids, the rate of flow of which has to be measured in practice and they may take the form of solid particles or gas bubbles in suspension. In cases where the flowing fluid itself is completely homogeneous, scattering elements can be introduced artificially, for example by producing cavitation in the body of the fluid.

This type of flowmeter can be used to measure the rate of flow of a liquid or slurry, for example, in a pipe, the rate of flow of an open liquid stream, for example the rate of tidal flow in an estuary past a fixed point, or other relative motion, such as the speed of a vessel in water.

In previous flowmeters of this type, which have been used for the measurement of fluid flow in pipes, the transducer or transducers may be arranged to generate ultrasonic waves directly in the fluid medium. Thus, a transmitting transducer may be mounted in a pipe elbow to direct a beam of waves along a section of the pipe. Alternatively, transducers may be mounted in cavities in the pipe wall to direct beams diagonally across the pipe.

Both these arrangements suffer from the disadvantage that the conditions of fluid flow are disturbed. In the second arrangement, there is risk of the transducer cavities becoming clogged by sedimentation. For both the above arrangements, the undisturbed sound velocity for the flowing fluid must be known.

Ideally, the temperature coefficient of sound velocity of the said medium in which the beam is generated should be zero, since the flowmeter error, due to changes of the velocity of sound in the flowing fluid, is then zero also. As the temperature coefficient increases, so does the flowmeter error. In any practical case, the term "low temperature coefficient of sound velocity" means a temperature coefficient of sound velocity for the medium in which the beam is generated which gives rise to a temperature error in the measured rate of flow less than the specified percentage accuracy of the flowmeter, between the limits of working temperature required.

In the most usual application of the invention, which is to the measurement of the rate of fluid flow in a pipe, the body which separates the transducer from the flowing fluid may be the wall of the pipe itself or an insert of solid material in the pipe wall. The transducer, or each transducer as the case may be, is then mounted in a cavity in the external face of the pipe wall or of the insert or it is otherwise mounted so as to direct a beam of ultrasonic waves obliquely into the solid material of the pipe wall or of the insert.

In the case of measurement of the rate of flow in an open stream of liquid, the transducer or transducers may be housed in a liquid-tight container, the separating body being the wall of the container. The container is then fixed, so that the liquid flows past it, such as by being fixed in the fixed duct or anchored in the estuary, as the case may be.

In circumstances in which the direction of flow varies, the container may be provided with vanes or fins so that it aligns itself with the direction of fluid flow.

In the case of measurement of fluid flow in pipes, when the transducer, or each transducer, is mounted externally against the pipe wall, if normal pipe materials are used, variations in the velocity of sound in the pipe material, caused by temperature change, will cause errors to occur in the flowmeter indication.

In most practical applications of the inven-

tion, particularly in such cases of the measurement of fluid flow in pipes and where the pipe wall is of normal thickness or the pipe material has a temperature coefficient of sound velocity which is not low, when compared with that of the flowing fluid, the separating body is provided by an insert in the pipe wall of a material having a low sound velocity and a low temperature coefficient of sound velocity as compared to that of the flowing fluid.

If the transducer is directly mounted on an insert in the pipe wall, it may be necessary to use a costly material such as gold or silver, which has low sound velocity and a negligible temperature coefficient of sound velocity as compared to that of the flowing fluid, in order to obtain a beam in the flowing fluid as required.

Cheaper materials are known which have a low sound velocity but which also have a temperature coefficient of sound velocity which is not negligible. An insert of such a material may be used in an alternative embodiment of the invention in which the transmitting transducer is mounted in a static body of liquid, externally of the pipe, to direct a beam of compressional waves onto the outer surface of the insert. This beam is converted, in part, into a beam in the insert and the beam in the insert is then converted in part, at the interface between the insert and the flowing fluid, into a beam of compressional waves in the flowing fluid.

This method is of general use in ultrasonic flowmeters in which it is required to adjust, or maintain, the angle of the beam in the flowing fluid with respect to the direction of flow. By adjustably mounting the transmitting transducer to vary the angle of incidence of the beam of ultrasonic waves upon the outer surface of the insert, the path of the beam through the insert and the angle at which the beam is refracted into the flowing fluid, may also be adjusted.

In order that the invention may be readily carried out, the principle of the type of ultrasonic flowmeter using the Doppler effect, to which the present invention is particularly applicable, and two embodiments of the invention, by way of example, will now be described in detail, with reference to the accompanying drawings of which:—

Fig. 1 is an axial cross-section of a pipe showing a known ultrasonic flowmeter arrangement having transducers mounted in internal cavities in the pipe wall;

Fig. 2 is a similar axial cross-section showing an ultrasonic flowmeter arrangement according to the present invention, having transducers mounted in external cavities in the pipe wall, and

Fig. 3 shows an axial cross-section of a pipe and an ultrasonic flowmeter arrangement according to the present invention, in which a single transmitting and receiving transducer is mounted externally of the pipe and the ultrasonic beam is directed into the flowing fluid through both a liquid body and an insert in the pipe wall.

In the arrangement of Fig. 1, a pipe 1 of normally used material carries a fluid medium 2 which flows through the pipe in the direction indicated by the broken arrow marked "Flow". A transmitting transducer 3 is mounted in an internal cavity 4 in the wall of the pipe 1 and directs a beam of ultrasonic waves into the fluid medium 2 at an angle ϕ_1 to the line of the pipe wall, that is at an angle ϕ_1 to the direction of flow. The centre ray of the beam is indicated at 5 and the marginal rays, in the section of the drawing, are indicated at 6 and 7. The beam is scattered by scattering elements in the fluid medium 2 in the region of the point 8. One scattered ray 9, which is reflected back at an angle of ϕ_2 to the direction of flow, returns to a receiving transducer 25 mounted in an internal cavity 26 in the pipe wall similarly to the transmitting transducer 3.

If an ultrasonic transmitting transducer is mounted in an internal cavity in the pipe wall to direct an ultrasonic beam of frequency f across the pipe at an angle ϕ_1 to the direction of the flow as in Fig. 1, the effective frequency of the wave relative to the scattering elements is given by:—

$$f_1 = f\left(\frac{c_1}{c_1 + kV\cos\phi_1}\right)$$

where c_1 is the undisturbed sound velocity, V the mean flow velocity, and k a constant depending on the position of the scattering element and the flow velocity profile.

The frequency f_1 of the scattered wave is thus a function of the sound velocity c_1.

A similar receiving transducer receives a scattered wave front reflected at an angle ϕ_2. The wave shows a frequency shift due to the Doppler effect and the frequency f_2 of the received wave is given by:—

$$f_2 = f_1\left(\frac{c_1}{c_1 - kV\cos\phi_2}\right) = f\left(\frac{c_1}{c_1 + kV\cos\phi_1} \times \frac{c_1}{c_1 - kV\cos\phi_2}\right)$$

The beat frequency $\triangle f = f - f_2 = f\left(1 - \frac{c_1}{c_1 + kV\cos\phi_1} \times \frac{c_1}{c_1 - kV\cos\phi_2}\right)$

Where an internal cavity-mounted compressional transducer is used, this expression applies. It will be seen that the beat frequency $\triangle f$ is dependent upon c_1, and that therefore

changes in velocity of sound propagation affect the beat frequency as well as changes in flow velocity.

In the arrangement of Fig. 2, the pipe 1 is made of a material which has a temperature coefficient of sound velocity which is negligibly small when compared with the temperature coefficient of sound velocity in a fluid medium 2 carried by the pipe and flowing in the direction of the broken arrow "flow". The pipe wall is thick and has an external cavity 4 in which is mounted a transmitting transducer 3. A similar receiving transducer 25 is mounted in an external cavity 26 in the same axial plane and opposite the transmitting transducer 3.

A beam of ultrasonic waves from the transmitting transducer 3 is indicated in Fig. 2 by the mid ray 10, 11 thereof. The beam 10 travels initially in the wall of the pipe 1 at an angle θ_1 to the axis of the pipe. At the interface between the pipe wall and the fluid medium 2, the beam 10 is refracted into the fluid medium 2 forming a beam 11, at an angle ϕ_1 to the axis of the pipe 1, that is at an angle ϕ_1 to the direction of flow. The beam 11 in the fluid medium 2 is scattered in the region of the point 8 by scattering elements in the fluid 2 and, of the scattered rays, a ray 12 is reflected at an angle ϕ_2 to the direction of flow and travels to the pipe wall. At the interface between the fluid medium 2 and the pipe wall, the ray 12 is refracted into the material of the pipe at an angle θ_2 to the pipe axis and the resultant ray 13 finally strikes the receiving transducer 25.

The transmitted beam 10 may be composed of compressional or transverse waves and in either case will be refracted, in part, into the fluid as a beam 11 of compressional waves.

With no flow and the incident beam at an angle θ_1 to the fluid-pipe interface, the refracted wave 11 will then be propagated at an angle ϕ_1 to the interface such that:—

$$\frac{c_p}{\cos\theta_1}=\frac{c_1}{\cos\phi_1}$$

that is:—

$$\cos\phi_1=\frac{c_1\cos\theta_1}{c_p}$$

where c_1 and c_p are the sound velocities in the fluid 2 and the pipe wall respectively.

If c_p is independent of temperature, $\cos\phi_1$ will thus be proportional to c_1.

With flow, there will be some distortion of the wave fronts but in most practical applications the effect is negligible, since V, the mean flow velocity, is very small compared with c_1 and thus the frequency of the refracted wave in the fluid 2, relative to a scattering element will be effectively:

$$f_1=f\left(\frac{c_1}{c_1+kV\cos\phi_1}\right)=f\left(\frac{c_1}{c_1+kV\cos\frac{\phi_1 c_1}{c_p}}\right)=f\left(\frac{1}{1+rkV}\right)$$

where

$$r=\frac{\cos\theta_1}{c_p}$$

Thus the frequency of the refracted wave f_1 will be independent of c_1 the velocity of sound in the fluid.

An identical refracting receiving transducer 25 is then used and a similar correcting effect takes place in the expression for received frequency, that is:—

$$f_2=\left(\frac{f_1}{1+skV}\right)\text{ where } s=\frac{\cos\theta_2}{c_p}$$

with the notation of Fig. 2.

The frequency difference between the incident and received ultrasonic waves is then:—

$$\triangle f=f-f_2=f\left(1-\frac{1}{1+(r+s)kV+rsk^2V^2}\right)$$

which is approximately equal to:—

$$f(r+s)kV$$

where, as in most practical cases, $\left(\frac{V}{c_p}\right)^2$ is negligible.

When the flow velocity profile is uniform k will be independent of the position of the reflecting or scattering centres across the pipe and $\triangle f$ will be independent of c_1.

In practice, it can be arranged that k can be regarded as a constant, even when there is a non-uniform velocity distribution across the pipe, in the flowing fluid. This is the case, for example with the arrangements of Fig. 1 and Fig. 2, in which the rays 5 and 9 and the rays 11 and 12 respectively intersect on the pipe axis.

For economy and simplicity, a convenient arrangement is to have $\phi_2=180°+\phi_1$, that is to receive the scattered or reflected waves by the same transducer as is used as the transmitter. This has the further advantage that the receiver receives the scattered or reflected waves from a greater number of the scattering elements in the fluid medium, with consequent enhancement of the received signal. In this case, the frequency spectrum of the

received signal will be effectively independent of c_1. Using suitable circuits, an output proportional to the rate of flow and independent of c_1 can be obtained.

Where the pipe wall has a significant temperature coefficient of sound velocity, inserts of material having a low temperature coefficient of sound velocity as compared to that of the flowing fluid can be used, the transducers being mounted in external cavities in the inserts.

In some cases there may be practical advantages in making $\triangle f$ as large as possible. This is achieved by making ϕ_1 and $180°-\phi_2$ as small as possible.

One method of achieving this condition is by using a diffraction transducer in which an array of suitable spaced small transducer elements are suitably spaced and phased to direct a beam in the desired direction. This type of transducer is difficult to construct at high frequencies, however.

A practical method consists in setting in the pipe wall an insert of a material having a low temperature coefficient of sound velocity and preferably low attenuation. Such materials to give ϕ_1 less than about 50° are gold, platinum, silver and high density lead glass. These materials are costly.

To avoid this difficulty, an insert in the pipe wall of a material with low sound velocity but with an appreciable temperature coefficient of sound velocity may be used, the ultrasonic beam being established initially in a liquid of negligible temperature coefficient of sound velocity and the beam then being directed through the insert into the flowing fluid.

Such an arrangement is shown in Fig. 3. In this figure, a pipe 1 carries a fluid medium 2 which flows in the direction of the broken arrow marked "flow". The pipe 1 is provided with an insert 24 of a material having a low sound velocity but which may have an appreciable temperature coefficient. Examples of suitable materials are polystyrene, and tin. Mounted on the wall of the pipe 1 enclosing the insert 24 is a metal container 20 which houses a transducer 23 and a liquid 21 having a negligible temperature coefficient of sound velocity. A suitable liquid is a 17% solution by weight of ethyl alcohol in water.

The transducer 23 is mounted on an inclined face 22 formed on the inner wall of the container 20 and directs a beam of ultrasonic waves of velocity c_0 through the liquid 21 at an angle θ onto a parallel plate insert 24. The mid ray is shown at 5 and the marginal rays, in the plane of the drawings, are shown at 6 and 7.

At the interface between the liquid 21 and the insert 24, the beam 5 is refracted in the material of the insert to set up therein firstly a transverse wave 15 at an angle α to the axis of the pipe 1 and having a velocity c_2 and secondly a compressional wave 17 at an angle γ to the axis of the pipe 1 and having a velocity c_3.

At the interface between the insert 24 and the fluid medium 2, the transverse wave 15 is refracted to form a compressional wave 16 in the fluid medium 2 at an angle ϕ_1 to the pipe axis.

The beam 17 is similarly refracted into the fluid medium 2 as a beam 18 of compressional waves.

The beam 16 is scattered in the region 8 by scattering elements in the fluid 2, and, of the reflected rays, one returns along the path of the forward beam 16. This returning ray follows the path 15, 5 until it strikes the transducer 23, which in this example, serves also as the receiving transducer. The return path is indicated by the reverse arrows in the figure.

With the notation of Fig. 3, the following relations then apply when there is no temperature gradient across the insert 24 or if the insert material has a zero temperature coefficient of sound velocity since the insert 24 has plane-parallel faces, then $\alpha=\beta$ for beam 15, $\gamma=\delta$ for beam 17. For beam 5, 15, 16:—

$$\frac{c_0}{\cos\theta}=\frac{c_2}{\cos\alpha}=\frac{c_2}{\cos\beta}=\frac{c_1}{\cos\phi_1} \quad (1)$$

For the beam 5, 17, 18:

$$\frac{c_0}{\cos\theta}=\frac{c_3}{\cos\gamma}=\frac{c_3}{\cos\delta}=\frac{c_1}{\cos\phi_1} \quad (2)$$

Because Equations (1) and (2) have the same initial term, all terms in both equations are equal. Hence, two emergent angles ϕ_1 are equal, and beams 16 and 18 are parallel.

With a temperature gradient in the insert normal to the insert to liquid interface, as will generally be the case, the equation:—

$$\frac{c_0}{\cos\theta}=\frac{c_1}{\cos\phi_1}$$

will still hold for the beams 16 and 18 even if the velocity of sound in the insert is temperature dependent.

When the value of θ in the Equation (2) above is such as to give a value for $\cos\gamma$ which is greater than unity, which is obviously not possible for any angle, the beam 17 is suppressed and a single beam 15 is propagated in the pipe insert 24. Such suppression of the compressional wave in the pipe insert may be

desirable to avoid interference effects due to multiple reflection of the compressional and shear waves in the insert. Also, such suppression will result when θ is arranged to give a minimum practical value for ϕ_1, as is sometimes required to obtain the maximum frequency difference between the transmitted and received waves, for a given flow velocity.

Usually, it will be convenient to predetermine the angle θ and mount the transmitting transducer in a fixed position, as at 23 in Fig. 3. If it is desired to adjust the angle ϕ_1, by adjustment of the angle θ, the transmitting transducer may be adjustably mounted for movement to the position indicated by 23^1 for example.

Where it is required to project a beam into a fluid in a pipe without modification of the pipe, the technique of Fig. 3 can be used without using an insert, the pipe wall remaining continuous. With or without an insert, there may be minimum practical values for θ and ϕ_1 depending on the pipe or insert material sound velocity and the sound velocities c_1 and c_0. The limitation imposed by the insert material sound velocity can sometimes be obviated by using an insert of a thickness which is small compared with the sound wavelengths in the insert material.

WHAT WE CLAIM IS:—

1. An ultrasonic flowmeter comprising a transmitting transducer arranged for directing a beam of ultrasonic waves into a body of flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, a receiving transducer arranged for receiving a part of the scattered beam, a solid body through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, and means responsive to the difference between the frequency of the waves transmitted by the transmitting transducer and the frequency of the waves received by the receiving transducer, the said frequency difference being representative of the rate of flow of the flowing fluid, the solid body being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

2. An ultrasonic flowmeter comprising a transmitting transducer arranged for directing a beam of ultrasonic waves into a body of flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, a receiving transducer arranged for receiving a part of the scattered beam, a fluid medium, other than the flowing fluid, coupled to the transmitting transducer for transmitting the beam, a solid body through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, and means responsive to the difference between the frequency of the waves transmitted by the transmitting transducer and the frequency of the waves received by the receiving transducer, said frequency difference being representative of the rate of flow of the flowing fluid, the said fluid medium coupled to the transmitting transducer being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

3. A flowmeter according to Claim 1 or Claim 2, in which the transmitting transducer also acts as the receiving transducer.

4. A flowmeter according to Claim 1 or Claim 2, in which said solid body is the wall of a pipe for carrying the flowing fluid.

5. A flowmeter according to Claim 4, in which said solid body is an insert in the wall of the pipe for carrying the flowing fluid.

6. A flowmeter according to Claim 2, in which the said fluid medium is a liquid.

7. A flowmeter according to Claim 6, in which the solid body is of a material having a low velocity of sound transmission relative to the velocity of sound transmission in the flowing fluid.

8. A flowmeter according to Claim 6 or Claim 7, in which the solid body has plane parallel opposite faces for forming interfaces respectively with the said liquid medium, and the flowing fluid.

9. A flowmeter according to any one of Claims 6 to 8, in which the solid body is an insert in the wall of a pipe for carrying the flowing fluid.

10. A flowmeter according to Claim 9, in which the transmitting transducer is mounted in a hollow container attached to the pipe wall, over said insert, and filled with the said liquid medium.

11. A flowmeter according to Claim 10, in which the transmitting transducer is adjustably mounted in the said container for variation of the direction of the generated beam of ultrasonic waves relative to the liquid medium to solid body interface.

12. A method of measuring the rate of flow of a flowing fluid, comprising the steps of directing a beam of ultrasonic waves from a transmitting transducer into a body of the flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, and receiving a part of the scattered beam, either by the said transmitting transducer or by a separate receiving transducer, the arrangement being such that the beam of ultrasonic waves is generated initially by the transmitting transducer in a solid body, through which the beam is arranged to be directed into the flowing fluid by refraction at the interface between the flowing fluid and the solid body, the solid body being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the fluid, so that

the difference of frequency between the transmitted waves and the received waves provides a measure of the rate of flow of the flowing fluid.

13. A method of measuring the rate of flow of a flowing fluid, comprising the steps of directing a beam of ultrasonic waves from a transmitting transducer into a body of the flowing fluid containing beam-scattering elements, at an angle to the direction of flow other than 90°, and receiving a part of the scattered beam either by the said transmitting transducer or by a separate receiving transducer, the arrangement being such that the beam of ultrasonic waves is generated initially by the transmitting transducer in a fluid medium other than the flowing fluid, and the said beam is directed into the flowing fluid by refraction at the interface between the flowing fluid and a solid body, the said fluid medium being selected to have a temperature coefficient of sound velocity therein lower than the temperature coefficient of sound velocity in the flowing fluid.

14. An ultrasonic flowmeter constructed and adapted to operate substantially as described herein with reference to Figure 2 or Figure 3 of the accompanying drawings.

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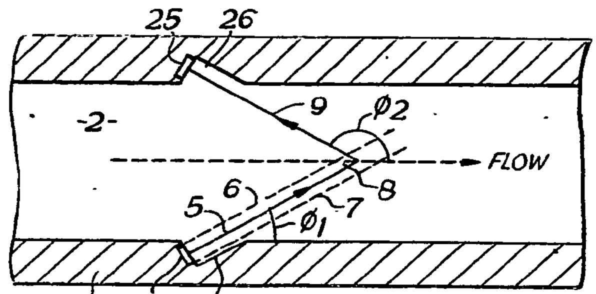
Leamington Spa: Printed for Her Majesty's Stationery Office by the Courier Press.—1963.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

Fig. 1.



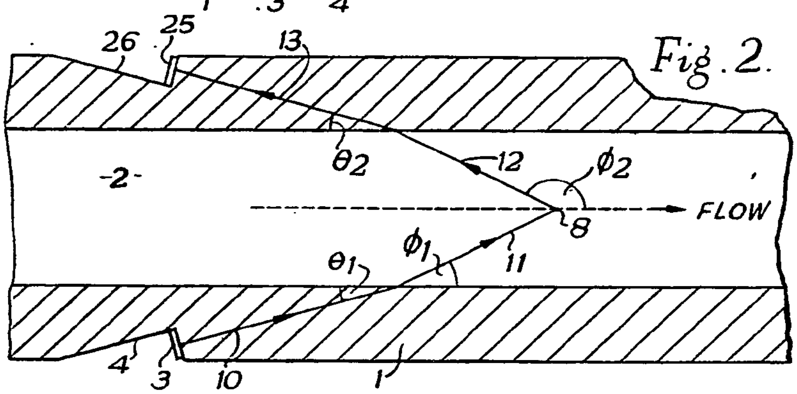


Fig. 2.

Fig. 3.